Fluid mechanics

Lecture 1:
Introduction and basic principles
General information

- Lectures: prof.dr.ir. J. Westerweel [ @wstrwl ]
  Tuesday 13:45-15:30
  Thursday 15:45-17:30
- Instruction: dr. R. Delfos
  Wednesday 13:45-15:30
- Book: Fluid Mechanics
  by Frank M. White
- Other sources: Multimedia Fluid Mechanics DVD (Cambridge)
  www.efluids.com
- Exam: April ??, 2012
  closed book exam, equation sheet provided
- Discussion: BlackBoard
  Twitter: #wb1225
Fluid mechanics in technology
Fluid mechanics in nature
Environmental fluid mechanics
Environmental fluid mechanics
Biological fluid dynamics

- chicken embryo
- wiggly take off

[16] [17]
Fluid mechanics in sports

[Image of bobsledders]
[Image of skier]
[Image of golf ball with flow visualization]
[Image of race car]
[Image of speed skater]
A 100 years ago and Today

Franz Reichelt, 1912

Jeb Corliss, 2011
Fluid mechanics in daily life
What is a fluid?

Image from Frank M. White - *Fluid Mechanics*
Fluid or solid?
Glacier flow

original

two years later
Flow visualization

Gary Settles

Van Dyke, Album of Fluid Motion
www.efluids.com

Gallery of Fluid Motion (Physics of Fluids)
Fluid properties

- Pressure \( p \) [Pa]
- Density \( \rho \) [kg/m\(^3\)]
- Temperature \( T \) [K]
- Thermodynamic properties:
  - internal energy \( e \), enthalpy \( h \), entropy \( s \)
  - specific heat \( c_p, c_v \) [J/K kg]
- Transport properties:
  - viscosity \( \mu \) [Pa s]
  - thermal conductivity \( k \) [W/K m]
Viscosity of common fluids

\[ \mu = \rho \nu \]

\( \mu \) = dynamic viscosity \([\text{kg/(m s)}]\) = \([\text{Pa s}]\)

\( \nu \) = kinematic viscosity \([\text{m}^2/\text{s}]\)

<table>
<thead>
<tr>
<th>Fluid</th>
<th>( \mu ), kg/(m \cdot s) ( ^\dagger )</th>
<th>Ratio ( \mu/\mu(H_2) )</th>
<th>( \rho ), kg/m(^3)</th>
<th>( \nu ), m(^2)/s ( ^\dagger )</th>
<th>Ratio ( \nu/\nu(Hg) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>8.8 E-6</td>
<td>1.0</td>
<td>0.084</td>
<td>1.05 E-4</td>
<td>920</td>
</tr>
<tr>
<td>Air</td>
<td>1.8 E-5</td>
<td>2.1</td>
<td>1.20</td>
<td>1.51 E-5</td>
<td>130</td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.9 E-4</td>
<td>33</td>
<td>680</td>
<td>4.22 E-7</td>
<td>3.7</td>
</tr>
<tr>
<td>Water</td>
<td>1.0 E-3</td>
<td>114</td>
<td>998</td>
<td>1.01 E-6</td>
<td>8.7</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1.2 E-3</td>
<td>135</td>
<td>789</td>
<td>1.52 E-6</td>
<td>13</td>
</tr>
<tr>
<td>Mercury</td>
<td>1.5 E-3</td>
<td>170</td>
<td>13,580</td>
<td>1.16 E-7</td>
<td>1.0</td>
</tr>
<tr>
<td>SAE 30 oil</td>
<td>0.29</td>
<td>33,000</td>
<td>891</td>
<td>3.25 E-4</td>
<td>2,850</td>
</tr>
<tr>
<td>Glycerin</td>
<td>1.5</td>
<td>170,000</td>
<td>1,264</td>
<td>1.18 E-3</td>
<td>10,300</td>
</tr>
</tbody>
</table>
The pitch drop experiment

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>The stem was cut</td>
</tr>
<tr>
<td>1938 (Dec)</td>
<td>1st drop fell</td>
</tr>
<tr>
<td>1947 (Feb)</td>
<td>2nd drop fell</td>
</tr>
<tr>
<td>1954 (Apr)</td>
<td>3rd drop fell</td>
</tr>
<tr>
<td>1962 (May)</td>
<td>4th drop fell</td>
</tr>
<tr>
<td>1970 (Aug)</td>
<td>5th drop fell</td>
</tr>
<tr>
<td>1979 (Apr)</td>
<td>6th drop fell</td>
</tr>
<tr>
<td><strong>1988 (Jul)</strong></td>
<td><strong>7th drop fell</strong></td>
</tr>
<tr>
<td>2000 (28 Nov)</td>
<td>8th drop fell</td>
</tr>
</tbody>
</table>

viscosity: $\mu = (2.3\pm0.5) \times 10^8 \text{ Pa s}$
(water: $\mu = 1.0 \times 10^{-3} \text{ Pa s}$)

http://drop.physics.uq.edu.au/PitchDropLive

Continuum hypothesis

\[
\bar{\rho} = \lim_{\delta V \to \delta V^*} \frac{\delta m}{\delta V}
\]
Shear stress

\[ \tau = \mu \frac{du}{dy} \]

deformation (strain) \([\text{s}^{-1}]\)

\[ \frac{d\theta}{dt} = \frac{du}{dy} \quad \text{(small } \theta) \]

shear stress [Pa]
Couette flow

stationary flow

Newtonian fluid ($\mu = \text{const}$):

\[ \frac{\tau}{\mu} = \frac{du}{dy} = \text{const} \Rightarrow u(y) = a + by \Rightarrow u = V \frac{y}{h} \]
Effect of viscosity
Reynolds number

\[ \text{Re} = \frac{\rho v L}{\mu} \]

\[ \text{Re} = 0.05 \quad 10 \quad 200 \quad 3000 \]
Non-Newtonian fluids

stress versus strain rate

effect of time on applied stress
Yield stress

Graph from Frank M. White - *Fluid Mechanics*
Shear-thinning fluid

Graph from Frank M. White - *Fluid Mechanics*
Visco-elastic fluid
Summary

• Chapter 1: 1.1-1.7, 1.11
• Examples: 1.5, 1.7-1.9
• Problems: 1.45, 1.47, 1.56
Sources

1. Face in the flame, http://www.flickr.com, photo courtesy of nEoPOL
18. Team Canada Bobsleigh, http://www.flickr.com, photo courtesy of ACGlab
26. Liquid sculpture 09, http://www.flickr.com, photo courtesy of Need to Focus
Illustrations from Frank M. White: Fluid Mechanics
Stills en movie fragments from Multimedia Fluid Mechanics DVD and Van Dyke, Album of Fluid Motion (www.efluids.com)